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Towards understanding the benefits and challenges of Smart/Micro-Grid for electricity supply system in Nigeria

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ABSTRACT

The poor state of electricity supply system in Nigeria is threatening the welfare and security of life and properties of millions of individuals with adverse economic consequences for the country. The inadequacy of the national grid, especially the inability of the electricity generation capacity to match increasing demand in the country has led to increasing agitation for increased penetration of renewable energy sources (RESs) into the electricity supply mix. While great attention has been focused on the potential of RESs for electricity generation in the country, little or no attention has been given to the application of Smart/Micro-Grid (SM-G) technologies to the ageing Nigeria grid infrastructures and electrification of the rural areas. The aim of this paper is to bring into focus the benefits and challenges of enabling SM-G in the electricity supply system in Nigeria. SM-G will bring benefits to the electricity stakeholders in form of improvements in reliability, efficiency, economics, environment, security and safety. The paper gives an overview and reviews the current state of the electricity supply system in the country. It discusses the SM-G concepts and associated technologies, and highlights how they can help address the electricity problems in the country. The challenges of applying these concepts in Nigeria context are also discussed. Enabling SM-G in the country will not only lead to improvement in the quality, efficiency and reliability of the electricity grid, but also promote the provision of electricity supply to the remote rural areas using RESs.

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1. Introduction

Electricity plays a significant role in economic growth and development of any nation and therefore serves as a bedrock of any modern society. Access to energy services such as lighting, heating for cooking and space heating, power for transport, water pumping and grinding are essential to both social and economic development and critical in achieving all of the Millennium Development Goals (MDGs) of reducing hunger and poverty by 2015 [1]. These services are made possible directly or indirectly by electricity. It is therefore worrisome that a large percentage of rural areas in Nigeria are still not connected to the national grid [2]. The only 10% of rural households and 40% of the country's total population that are presently connected to electricity grid [3], are facing a highly unreliable, frequent outages, blackouts or brownouts, and total breakdown that can last weeks or even months.

The lack of access to the grid in the rural areas and poor power qualities to the on-grid areas have led to many houses in the country becoming a mini power generation station using mostly fossil fuel sources. Many people have lost their lives from the fumes of generator ignorantly left running overnight in the sitting room, and in some cases, a whole family has been wiped out of existent. Industrial consumers are also investing huge resources in the installation and maintenance of generators as alternative source of power to overcome the unreliable power supply from the nation's electricity grid. Those that cannot afford the high installation and maintenance cost of standalone generators have moved their businesses to the neighbouring countries, causing a huge economics loss to the country.

The global climate change leading to growing demands to reduce carbon emissions, places further constraints on electricity power network already facing multiple challenges. Obviously, Nigeria is facing an unprecedented electricity crisis and despite recent investment efforts on the grid infrastructures by the Federal Government, the crisis remains unabated and no tangible results have been felt by Nigerian.

For meaningful economic development and foreign investments in the country, the present poor quality and inefficient power supply system in the country need to be addressed. It is therefore mandatory for the national grid to undergo changes over the short, medium and long term. These changes have already started to take place through the introduction of a number of reforms and policies in the electric power sector by the Federal Government, namely, unbundling and privatisation of electricity sector, allowing Independent Power Projects (IPPs) to generate and sell to the national grid, and the development of Renewable Energy Master Plan (REMP), among others.

The general aims of the reforms in Nigeria like deregulated electricity industries in other countries across the globe are to improve efficiency, to create a more competitive energy-producing industry, to attract new – outside – investors and also to divest the state of over-regulated, and often heavily indebted, electricity undertaking, providing welcome cash for the government that can be spent on social services [4–6]. The development of REMP and the growing demand for increased penetration of RESs into the Nigeria electricity supply mix [7,8] are attributable to the availability of abundant and diverse renewable energy sources (RESs), such as solar, wind, hydroelectric, tidal and biomass in the country.

Nigeria is not the only country advocating for increased penetration of RESs into the electricity grid. Due to increasing shortage of the fossil fuels and the desire to reduce carbon emissions, RESs, especially wind and solar power, are becoming increasingly important in the electric power generation across the globe. For example, in California, US, RES generation is compulsorily required to occupy 20% by 2017, while a 15% proportion of the RES generation will be achieved by 2020 in China according to the government report, and in Germany the wind power generation will amount to 60% by 2020 [9,10]. In line with the world trend, Nigeria has also set a target through her REMP road map to achieve 13%, 23% and 36% of her electricity generation from RESs over short, medium and long term [11].

Worldwide, there is also considerable interest in Smart Grid (SG) due its capabilities to help in the reduction of carbon emissions, improving energy saving and efficiency, and integrating a broad range of generation and Electrical Energy storage (EES) options including RESs [12]. This has led to a significant investment in research and development on SG technologies [13] and many emerging SG projects in Europe, US and China. Microgrids (MGs) are seen as starting point for SG and good way to demonstrate its capabilities (this explains why SM-G is used when referring to both in this paper). It is expected that MG will reach over 3 GW of accumulative global capacity by 2015 [14].

Despite the benefits of SM-G, there is presently no plan for SM-G investments in Nigeria. We argue that application of SM-G to the electricity power grid in Nigeria is a viable option for the transformation of her existing national grid into a more efficient and reliable system. SM-G technologies can help solve the problem associated with integration of intermittent power generated from RESs; allow the creation of MGs in both on-grid and off-grid fashion, and permit easy operation of small power producers from the consumers. On-grid MGs will help in strengthening the existing grid, while off-grid MGs will help supply the remote rural areas in most economical way thereby pave the way for private investors to participate in the electrification of the rural areas in the country. It is therefore important for Nigeria to move with the rest of the world by focusing on how these technologies can be applied to modernise her ageing electricity infrastructures. This article aims to bring these technologies to the forefront in the quest to solve current electricity challenges in the country. In particular, we want to bring into focus the benefits and challenges of enabling SM-G technologies in Nigeria electricity supply system with the aim of stimulating further discussion and research.

The reminder of the article is organised as follows. A brief overview and review of the current state of the national electricity grid in Nigeria are presented in Section 2. In Section 3, SM-G and associated technologies are discussed, while in Section 4 the benefits of SM-G to the electricity stakeholders are presented. The challenges of enabling SM-G in the country are dealt with in Section 5 and the paper ends with conclusions in Section 6.

2. Overview and current state of Nigeria electricity supply system

Nigeria electric power supply system has been until recently under the monopoly of Federal Government as enshrined in Decree 24 of 1972. The Decree gives the sole custodian of electricity power supply system in the country to the National Electric Power Authority (NEPA), now called Power Holding Company of Nigeria (PHCN). PHCN is a vertically integrated utility responsible for power generation, transmission and distribution (T&D) of electricity to various types of consumers (residential, commercial and industrial). The transmission system (about 11,000 kilometres in length) supplies bulk power from the power generating stations to the distribution substations at high voltages (132–330 KV), while the distribution system delivers power from these substations to the consumers' doorstep predominantly at various voltages (33 KV, 11 KV, 415 V and 220 V) [15] and [16].

With the coming into force of the Nigeria Electric Power Sector Reform Act (EPSRA) of 2005, the vertically integrated Nigeria power sector utility – PHCN has been separated into generation, transmission and distribution companies [17]. The Act stipulates the functional unbundling of the generation, transmission and distribution sectors. The unbundling of PHCN has resulted into 6 generation, one transmission, one Nigerian Bulk Electricity Trading Plc. and 11 distribution successor companies [18]. EPSRA provides an enabling regulatory framework for private sector participation in the electricity industry in Nigeria. The Act also provides the establishment of a regulatory body – National Electric Reforms Commission (NERC) to facilitate the privatisation of the successor companies as well as the gradual development of a competitive and privately managed electricity sector [5]. In addition to the newly created generation companies, a number of privately financed Independent Power Projects (IPPs) are emerging and many others have been licensed by the NERC [19]. To better understand the importance and benefits of SM-G to the electricity supply system in the country, we briefly summarise in this section the major problems facing the various sectors of the power supply system in the country. A detailed study and discussion of these problems have been carried out by many workers [8,20–28].

2.1. Generation

Nigeria is heavily dependent on large-scale electricity production from hydro, oil, natural gas and coal generation stations. The electricity generation mix is circa 39.8% gas, 35.6% hydro, 24.8% oil and 0.4% coal as depicted in Fig. 1. The generation capacity from these sources cannot match increasing demand in the country. The available generation capacity has consistently stayed below the installed generation capacity as illustrated in Fig. 2. The current total installed capacity of the generating plants stands at 7876 MW, but the installed available capacity is less than 4000 MW [24]. This is a reflection of inefficiencies in the generator segment of the electricity power supply system in the country.

Despite the massive level of investment on additional generation stations and IPPs, the gap between demand and supply continues to widen sharply. Reasons for this have been attributed to inadequate gas supply to the thermal stations, shutting down of gas plants for maintenance, gas pipeline vandalisation, shortage of water in the dams, generator shut down for repair works and vandalisation or theft of power equipment and cables. There is no doubt that the current available peak power cannot satisfy the demands of Nigeria population of over 160 million people. The possibility of the generation capacity meeting the projected demand of 26,561 MW by 2020 is also in doubt [29]. The heavy dependent of Nigeria on large-scale electricity production makes the planning and construction cost of new generating plants extremely expensive. To that is the overriding constraint and bottlenecks in the power T&D networks.

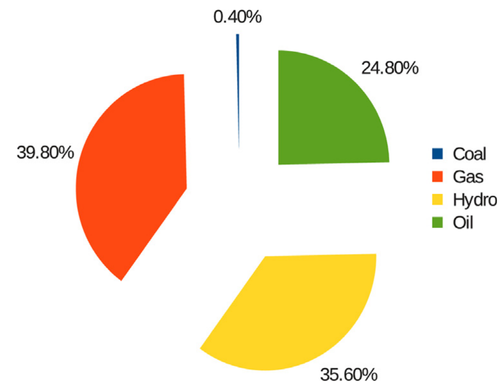

Fig. 1. Percentage contribution of energy sources to electricity generation mix in Nigeria. (Data source: [30]).

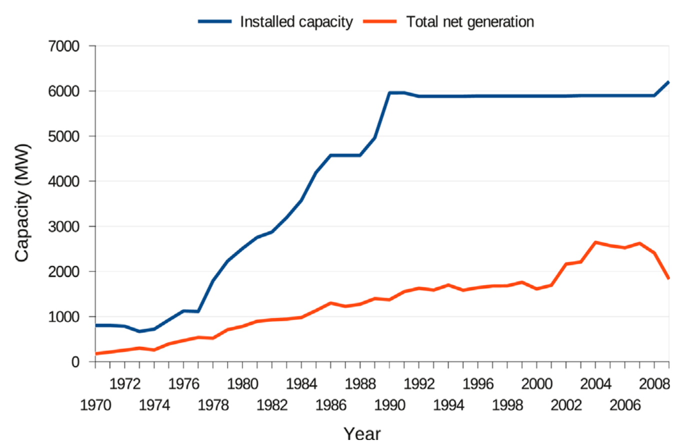

Fig. 2. Installed and available generation capacity in Nigeria from 1980 to 2009 (Data sources: [31–33]).

2.2. Transmission

The transmission network is an important link between the generating stations and the distribution stations. It is there worrisome that its present wheeling capacity is grossly inadequate to evacuate the little available generation capacity to the distribution stations serving the grid-connected consumers. The transmission system currently has the capacity to transmit less than 5000 MW and it is technically weak thus very sensitive to major disturbances and prone to frequent collapses [24]. A high percentage of the generated power is lost during transmission before it reaches the customer premises. The huge power loses reduces considerably the actual power that reaches the consumers leading to very poor power quantities and qualities. Fig. 3 shows the power losses in T&D wires along with the net electricity

generation for the period between 1980 and 2008. Translated into percentage of the net generation, the power losses in T&D fluctuate between 9% in 2008 and 46.9% in 1996. Although, the poor conditions of the T&D network are mainly to blame for this, other major contributing factors to the system losses are non-technical factors, such as inaccurate metering and billing, un-metered supplies and non-payments of electricity bills [33]. The transmission line fault detection method is also very poor with no capability to know the specific location of a fault that occurs in the lines. A huge investment will be required to boost the transmission network to cope with the present and planned generation capacity.

2.3. Distribution and sales

The distribution systems are the main point of contact of the electricity utilities to the consumers. They have offices around the major towns and cities with no tangible benefits to the consumers. The employees at the distribution offices are responsible for the operation and maintenance of distribution system infrastructures but they are not well equipped to perform their jobs and very incapable of handling electricity consumers' problems. They work with outdated equipment, tools, safety facilities and operational vehicles [34]. The voltage profile at the electricity distribution points is very poor due to power losses in T&D wires (as discussed in Section 2.2) and overloaded transformers. Most of the power interruptions and outages occur at the distribution levels without the benefit of any prior warning to the consumers. Manual report of power failures by the consumers takes many days or even months to be rectified.

There is no proper energy management at the distribution level, no reliable real-time data about the state of the distribution systems, and no properly automated and coordinated controls to take immediate and decisive action against failure events in an effort to prevent cascading [22]. Distribution transformers are therefore subjected to frequent breakdown because there is no information at the base station on the loading and current status of the transformers and associated feeders [25].

Despite the poor power supply, the electricity tariffs keep on increasing. The average electricity tariff for each category of consumers (residential, commercial and industrial) supplied by Benin distribution company is depicted in Fig. 4A (fixed charge) and B (energy charge). The yearly tariff increase is also applicable to consumers serviced by other distribution companies in the country. Accurate calculation of electricity bills based on these tariffs is a huge problem due to inadequate and outdated metering systems at the consumer premises. This is in addition to very poor billing methods with lots of fraudulent practices in the billing. For instance, consumers without electricity meters are forced to pay a fixed monthly electricity bill, whether there is power supply for the whole month or not. Those with electricity meters are faced with overestimated billing, illegal disconnections and connections, extortion and poor meter reading [34] and [35].

While the grid-connected areas of the country are daily facing inefficient and unreliable power supply system, a large percentage of Nigeria populace that are not connected to the national grid are left to their own faith. These are the people mainly residing in remote rural areas. Connecting them to the national grid is presently not economically attractive due to the high cost of grid extension. The erratic power supply to the consumers and the need to electrify the rural areas combined with the growing demand to reduce carbon emissions from fossil fuel sources, which are rapidly being depleted, make it mandatory for Nigeria to look in the direction of the distributed generation (DG) to tackle the electricity problem in the country.

2.4. Distributed generation

There are many definitions of DG. For the purpose of this article, we will stick with a general definition as in [37], which defines DG as electric power generation within distribution networks or on the customer side of the network. DG can be connected to the grid or provides power to off-grid isolated rural areas. The interconnection of DG to the grid provides a variety of advantages, including on-demand power quality of supply, enhanced reliability, deferrals in transmission investment, and avenues for meeting renewable mandates in the face of growing disinvestments in transmission assets [38,39]. The recent deregulation and restructuring of the PHCN, availability of verse RESs, technological advancement, rural electrification, and the growing demand for reduction in carbon emissions, among others will accelerate the adoption of DG in Nigeria. The main driver of DG

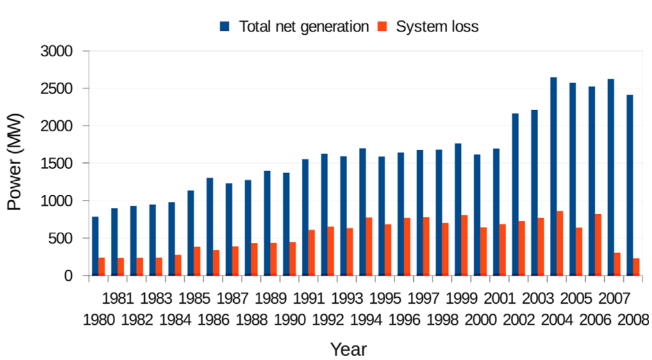

Fig. 3. System losses in relation to net generation capacity (Data sources: [32,33]).

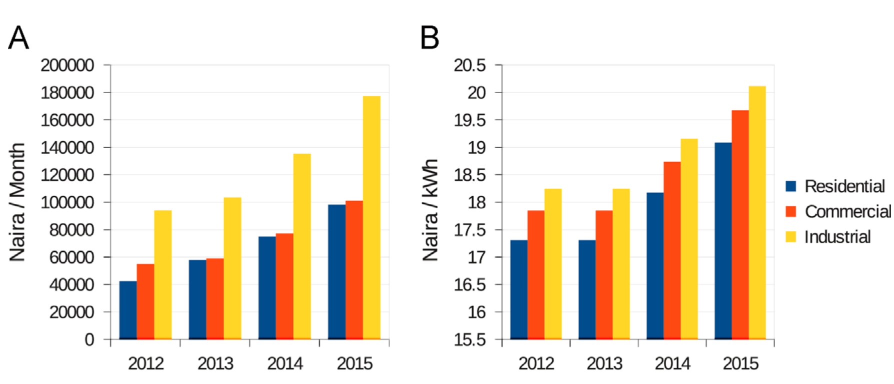

Fig. 4. Average tariff for different categories of consumers served by Benin distribution company (Data source: [36]).(A) Fixed charge and (B) Energy change.

will be from RESs led by solar, wind and Small Hydro Power (SHP) sources. Others are biomass and bioelectricity. The electrification of the rural areas, where national grid cannot easily be extended due high cost and bad access road will significantly benefit from this.

Nigeria is endowed with abundant RESs in nearly all part of the country. RESs are sustainable, limitless and environment friendly. The potentials of electricity generation from RESs in Nigeria have been demonstrated in several studies, separately; solar [2,29,40], wind [41–45], SHP [46–48], and jointly [3,49–51]. In recognition of the importance of RESs in electricity generation, the REMP road map targets an increase in renewable-energy contribution to electricity generation in Nigeria over short, medium and long term as shown in Table 1. This is a major step towards addressing the gap between electricity supply and demand in the country. However, DG powered by RESs can pose potential negative consequences to electric system operations, particularly when units are not dispatchable, or when local utilities are not aware of DG operating schedules, or when the lack of proper interconnection equipment causes potential safety hazards [52]. In addition to that, there is lack of appropriate business model for supplying the rural areas. SM-G can help overcome these difficulties by effectively harnessing the abundant RESs to bridge the huge gap between demand and supply of electricity in the country as well as permit efficient operation of the T&D networks leading to efficient and reliable electric power supply in the country.

Table 1
Targets for renewable energy contribution to electricity generation in Nigeria [53].

Renewable energy sources	Short – 2015 (MW)	Medium – 2020 (MW)	Long – 2030 (MW)
Large Hydro Power (LHP)	4000	9000	11,250
Small Hydro Power	100	760	3500
Solar Photovoltaic	300	4000	30,005
Solar Thermal	200	2136	18,127
Biomass	5	30	100
Wind	23	40	50
All Renewable Sources	4728	15,966	63,032
All Energy Sources	47,490	88,698	315,158
% of Renewable Sources	10	18	20
% Renewable minus LHP	1.3	8	16

3. Smart/Micro-Grid technologies

This section provides a brief description of the main concepts of SM-G and discusses the required technologies for enabling these concepts in Nigeria.

3.1. Smart Grid

The Smart Grid (SG) refers to a generic power network that is able to smartly integrate the actions of all the elements connected to it (DGs, loads, EES systems, protection, and control systems) through a coordinate process that ensures the optimal electrical energy generation, transmission, and distribution in an efficient, safe, and economical way [54]. SG has advanced two-way communication capabilities for smart metering and monitoring of

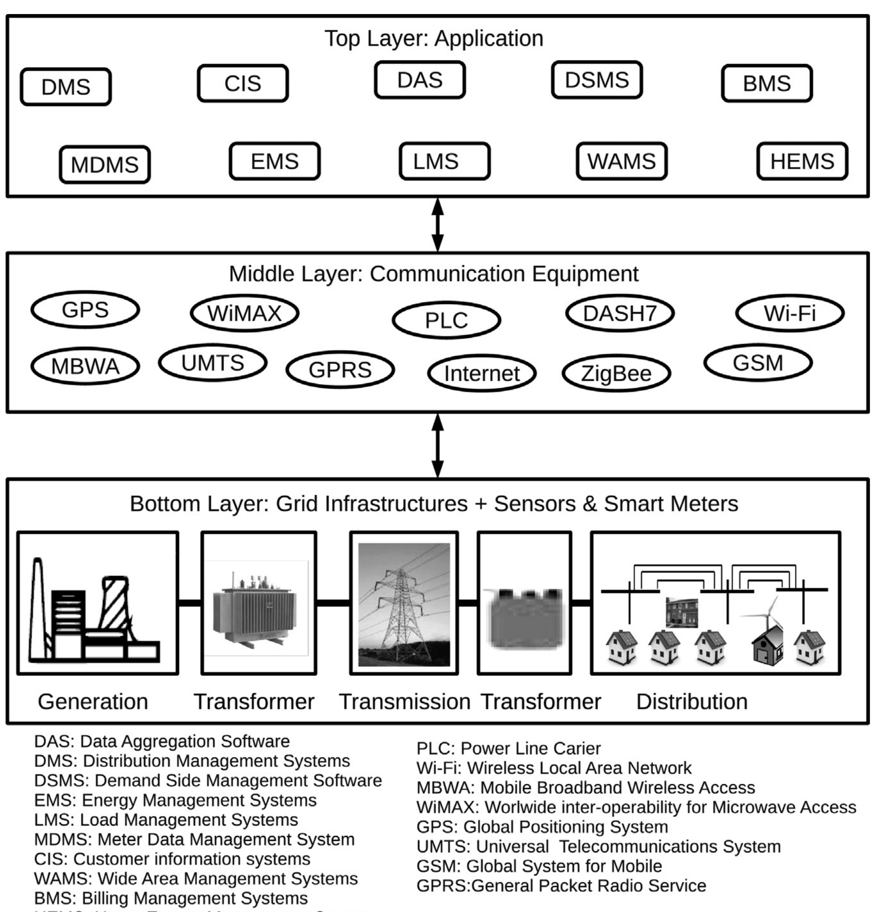

Fig. 5. A schematic representation of three-layered architecture of Smart Grid.

equipment, such as generators, transformers, transmission lines and other data gathering devices. Its key feature is automation technology that lets the utility adjust and control each individual device or millions of devices from a central location [55].

SG is basically a three-layered architecture system, consisting of communication equipment at the middle layer that enables two-way communications between the bottom layer (the traditional grid infrastructures plus intelligent sensors that collect information about the status and operations of the grid infrastructures) and the software or application layer that allows for aggregation and analysis of the collected data [56]. A schematic representation of the SG architecture showing the possible internal compositions of each layer is depicted in Fig. 5.

SG core characteristics that make it different from the current grid are self-healing, active participation of all types of customers, accommodation of all generation and storage options, enables new markets that support both wholesale and retail electricity markets, resilient to attacks and natural disaster, and provision of enhanced power quality. The key technologies that enable these characteristics have been discussed extensively in Refs. [57–64]. These include Advanced Metering Infrastructure (AMI), Demand Response (DR), Customer Side System (CSS), Advanced Distribution Automation (ADA), Transmission Enhancement Applications (TEA), Asset/System Optimisation (AO), Distributed Energy Resources (DER) and Information and Communication Integration (ICI).

Nigeria has recently completed the deregulation and privatisation of its electricity power sector and there are presently no SG projects in the country. However, many existing or planned rural electrification projects across the country (Section 3.2 below gives examples of these projects) can be used as starting points for MG projects for the off-grid communities.

3.2. Microgrid

MG is a group of interconnected loads and DERs within clearly defined electrical boundary that acts as a single controllable entity with respect to the grid [65]. MGs provide platforms for integrating RESs into the distribution systems [66] or supplying electric power to isolated rural areas using available RESs. MGs can play a significant role in overcoming the major challenges on the use of RESs in Nigeria by coordinating the production of power from many very small power producers, such as the owners of rooftop solar panels or wind farms through the use of intelligent devices and technologies.

MGs may or may not have access to the larger electricity grid. However, in the context of this article, a MG without access to larger grid will still have a point of common coupling for future connection to the larger grid. This type of MG is usually designed for remote off-grid rural areas using available DGs. MG can also be formed for academic institution (university campuses, polytechnics and primary schools) or hospitals (state, teaching and federal hospitals, and health centres) or public community (isolated rural areas, farm settlements and on-grid communities) or industrial/trading/commercial estates to cater for their energy needs in case of power failure from the larger grid. Utility MGs can also be formed as part of the distribution systems to provide local support to the load under grid failures, peak hours, and poor quality instants [67]. MG combined with DERs can be a preferable solution to the rural electrification in Nigeria as well as a complement to nowadays centralised modern and smart power grids [10,68].

A number of rural electrification projects (Table 2) using different forms of RESs are already available in various parts of the country. There are also other rural electricity projects for community infrastructures, built for education, skills acquisition, environment, health, rural electrification, transport, and water, and also rural market infrastructures in different parts of the country. Several other potential sites for electricity generation using SHP, Solar and Wind have also been identified across the country. For example, SHP potential sites exist in virtually all parts of Nigeria with an estimated total capacity of 3500 MW [69]. This is clearly an indication that nearly all parts of the country are well suitable for MG projects. Existing rural electrification projects can serve as starting points for the development of MG projects and experience gained from there can be used to develop further MG projects for other off-grid rural communities. Rather than focusing mainly on building large centralised power plants and associated T&D infrastructures with the high investment and long construction cycles, the available RESs in the country can be utilised to construct MGs. Several MG business models that can be used for electrification of the off-grid rural areas have been discussed in Ref. [70].

Table 2
Examples of rural electrification projects in Nigeria using renewable energy sources [27,71,72].

Project type	Location	Rating in kW	Energy source
Village electrification	Sayya Gidan Gada, Sokoto	5	Wind
Village electrification	Durumi, Surburb of Abuja	3	Solar
Village electrification	Kwalkwalawa, Sokoto	7.2	Solar
Campus electrification	University, Sokoto	1.5	Solar
Internet back-up	Nunet, University, Sokoto	2	Solar
School electrification	Kaduna	5	Solar
Communication & electrification	Mechanized Brigade, Kano	1	Solar
Communication & electrification	Kaduna	1.5	Solar
Street lighting	Uyo, Cross River	–	Solar
Electrification	Ganjuma, Bauchi	150	SHP
Electrification	Enugu	30	SHP
Electrification	Kakara, Sarduna, Taraba	400	SHP
Electrification (ongoing project)	Benue	435	SHP

MGs allow for distributed generation and local demand balancing to enable the grid to be built up neighbourhood by neighbourhood [73]. Neighbourhood by neighbourhood construction of MGs for off-grid communities in Nigeria will lead to interconnected larger MGs with single point of connection to the national grid. The concept of MG interconnections will be more economically attractive to private investors compared to isolated MGs. The regulations permitting private investors to establish electricity distribution networks [74] will accelerate this type of MG applications in the remote rural areas. Smart devices will simplify the management and control of the MG systems as well as reduce the cost of maintenance of the remote MGs. A potential advantage of this approach is that it should facilitate more imaginative schemes for meeting the local requirements in a flexible manner with the small-scale generators and consumers closely integrated [75].

4. Smart/Micro-Grid benefits to Nigeria electricity supply system

SM-G combined with the liberalisation of PHCN would open up opportunities for consumers to use RESs to meet their own electricity needs, as well as owners of the PCHN successor companies to explore possibilities to overcome electricity challenges with DERs. SM-G offers capabilities to tackle the various problems confronting all aspects of Nigeria electricity supply system, from generation up to consumer premises including the

Table 3
Major problems facing the electricity supply system linked to SM-G technologies for addressing the problems.

Major problems in electricity supply system	SM-G technologies								
	AO	TEA	ICI	ADA	DR	AMI	CSS	DER	MG
Ageing infrastructures	✓	✓	✓	✓	✓	✓	✓	✓	✓
Manual billing & poor metre reading, overestimated bills			✓			✓	✓		
Power theft/vandalism including illegal disconnections & connections			✓	✓		✓			
Manual fault detection & reporting		✓	✓	✓		✓			
Inadequate generation capacity	✓		✓		✓			✓	✓
Use of large-scale fossil fuel generators					✓			✓	✓
Huge installation cost for generation and associated T&D systems					✓			✓	✓
Very high power losses at T&D levels		✓	✓					✓	✓
Overloaded transformers leading to frequent breakdowns		✓	✓	✓	✓			✓	✓
Transmission bottlenecks	✓	✓	✓	✓	✓			✓	✓
Inefficiency & poor management		✓	✓	✓	✓	✓	✓	✓	
High rate of interruptions, disturbances & blackouts	✓	✓	✓	✓	✓		✓	✓	✓
Low voltage, poor power qualities at customer premises		✓	✓	✓	✓		✓	✓	✓
Lack of real-time data sharing		✓	✓	✓		✓			
High use of diesel generators						✓	✓	✓	✓
Lack of electricity supply to rural areas			✓			✓	✓	✓	✓

easy management and control of isolated electricity supply to the rural areas. The major problems confronting the electricity supply (discussed in Section 2) are best tackled by the SM-G technologies presented in Section 3. Table 3 shows these problems linked to candidate SM-G technologies for addressing them. This many- to-many relationship between the technologies and the problems means that more than one technology may be required to address one problem and one technology can participate in solving more than one problem.

Aside from tackling the problems, SM-G will bring enormous benefits to the electricity stakeholders in the country. The stakeholders include the utilities (GENCOs, IPPs, TCN and DISCOs), consumers, off-grid rural communities and society. The benefits will come in form of improvements in key value areas, such as reliability, efficiency, economics, security and safety [58]. The key value areas including cost and benefits of SM-G have been analysed and discussed extensively in [14,76–80]. Here we briefly relate the key value areas to the electricity supply system in Nigeria and highlight the benefits to expect by the stakeholders in the country.

4.1. Reliability

A reliable national grid is expected to perform its required function of electricity delivery to the consumers, as they need it. However, it is evident from the earlier discussion that the fulfilment of this function is far from being met by the current national grid. The implementation of SM-G technology would help overcome the reliability problem in the country. This will reduce the frequency and duration of power outages, the number of disturbances that occur due to poor power quality, and would make widespread blackouts a thing of the past.

4.2. Efficiency

As described earlier, the operation of the present national grid is characterised with high-level of inefficiency and fraudulent practices. While the privatisation of the national grid will reduce the level of fraud in its operation, SM-G is an effective way to overcome the inefficiency in the national grid. Transforming the grid through SM-G technologies will lead to a self-healing system with ability to perform continuous self-assessments to detect, analyse, respond to, and as needed, restore grid components or network sections. Efficiency will improve through well-coordinated energy and capital investments, and reduction in total energy use, peak demand and energy losses. SM-G provides capability that can induce end-users to reduce electricity use instead of relying upon additional installation of new large-scale generation [58].

4.3. Economics

A number of studies on cost benefits analysis of SG showed that countries could make huge financial saving on SG investment over the existing grid. For instance, a study on economic benefits of SG for British economy shows that Great Britain is expected to save around $30 billion net of present value [81]. A similar study in USA by the Electric Power Research Institute (EPRI) [77] concludes that the net benefits (e.g., productivity, quality of life, security and reliability) of enabling a fully functioning SG for about 130 million homes in US are as high as $2028 billion [82]. The net benefits of SM-G to Nigeria are expected to be higher considering the present state of her electricity supply system. In general, it is expected that improvements in operating efficiencies of the utilities will reduce their operation, maintenance and capital costs leading to numerous benefits to all the stakeholders. The current passive role statue of consumers with little or no contributions to the operation of the national grid will change to a more active one where they can assume the role of electricity producers/suppliers through decentralised generation technologies from RESs, such as wind turbines and solar panels to generate electricity at the household and community levels [12].

4.4. Environment

The emissions generated during the different phases of electricity production, transport and distribution depends on the characteristics of the technology under consideration as well as the quantity of fossil fuels used [83]. The poor qualities of electricity supply system in the country have led to many individuals and industries to rely on diesel-based generators. This and the large-scale electricity generation from fossil fuels are great obstacles to the reduction of carbon emissions. The impacts of the consumption of fossil fuels on the environment will be reduced through optimisation of flow from existing generation facilities and removing inefficient resources.

The use of DER technologies driven by SM-G technologies will deliver clean and more efficient power at a cost [58] far less than diesel-based generators. This will reduce the dependency of the national grid on the large-scale generation from the fossil fuel

sources. Increased utilisation of clean RESs for electricity generation enabled by the SM-G technologies and concepts is a promising way to reduce carbon footprints.

4.5. Security and safety

The SM-G continuously monitors itself to detect unsafe or insecure situations that could detract from its high reliability and safe operation. Improvements in security will increase the robustness and resiliency of the grid from a physical perspective. This will reduce the probability and consequences of man-made attacks and natural disasters [58].

4.6. Benefits to stakeholders

The benefits to the stakeholders are summarised as follows.

4.6.1. Utilities

SM-G will provide great opportunities for the utilities to provide more reliable energy, particularly during challenging emergency conditions, while managing their costs more effectively through efficiency and real-time data. High reliability means, increase in the uptime of generators for the suppliers and hence more sales. SM-G will provide easy detection of power theft and vandalisation of electricity equipment due to easy monitoring by the grid operators. The real-time communication between utilities and consumers allows easy detection of any tampering with the metering equipment, or bypassing of electricity meters, or any attempt to tamper with other transmission and distributed equipment. More efficiency will lead to reduction in the cost of distribution and transmission system operations. The ability of the consumers to reduce load demand in response to emergency and high prices will lead to reduction of stress on the system assets during peak conditions, reducing their probability of failure and breakdown. It will make intermittent RESs more viable, thereby increasing their percentages in the national grid. DR is also useful in maintaining electric service when the delivery system is stressed, reducing the probability of an outage or an electrical failure, both of which have health and safety implications [58].

4.6.2. Consumers

Consumers will benefit from easy measurement and control of small-scale private electricity production. They can balance their energy consumption with the real-time supply of energy and up to date information on electricity prices. Variable pricing and DR will provide consumer incentives to install their own infrastructure that supports the SG. SG information infrastructure will support additional services not available today [77]. The influence of consumers in electricity market will increase, as tools are available to them for participation in efficient utilisation of energy [63]. Providing consumers with access to readily available metered electricity usage information may help them evaluate and quickly decide when and how they use electricity. This knowledge could possibly result in energy savings and lower bills or enable greater participation in DR programs [80]. Customers will enjoy a reduction in the frequency and duration of power outages as a result of reliability improvement. The number of disturbances that occur due to poor power quality will reduce with a dramatic reduction in widespread blackouts or brownouts.

4.6.3. Rural communities

A large percentage of the rural areas in Nigeria are presently not connected to the national grid. This can be attributed to high cost of grid extension to these areas as earlier mentioned. The availability of RESs in the country provides a good opportunity for effective energy decentralisation and security to both rural and urban citizens. Luckily, RESs such as wind, solar PV, biomass and SHP are, in general, well distributed over the country [3]. The use of MG with high content of RESs is a very viable option for electrification of remote villages and farm settlements far away from the national grid. MG can provide an economic basis for participation of the private investors in electrification projects in remote areas. The ability to provide electricity supply to both national grid and off-grid rural areas makes MG a good candidate business model for harnessing the RESs in Nigeria. Hybrid-MG systems, which combine two or more different but complementary energy supply sources at the same site, can provide relatively constant electricity at an affordable cost to the remote rural communities, even when one of the supply systems is shut down [3]. By virtue of good match between generation and load, MGs have a low impact on the electricity network, despite a potentially significant level of generation by intermittent RESs [75]. A community smart MG can integrate all on-site RESs, EESs, and demand-side-management technologies to meet the exact energy needs of the community through real time energy management. This will allow the community to maximise energy savings [58].

MGs can promote the electrification of the rural areas in Nigeria in similar way to MG projects in Senegal [84] and Kenya [85]. The recent publication of regulations by the Federal Government through the NERC that enable local and state governments, communities and even individuals to generate and distribute electricity within their areas will positively impacts the use of MG in Nigeria [74].

4.6.4. Society

The society will benefit from more reliable power for governmental services, businesses, and consumers sensitive to power outage. Renewable Energy (RE), increased efficiencies, and Plug-In Electric Vehicle (PEV) support will reduce environmental costs, including carbon emission [77]. A more reliable power supply will lead to a dramatic reduction in the cost of blackout in the country. Blackout cost in Nigeria is in the region of billions of US dollar. For example, the cost of running diesel generators for powering many telecommunication service base stations across the country could be in the region of $2.0 billion. The economic development of any nation depends on a reliable and high quality source of electric power. SM-G will boost the level of economics development in the country

The level of crime in the country will also reduce due to reduction in the number of hidden places for criminals and the availability of employment for many unemployed people in the country. SM-G will give opportunity for the economic to grow through creation of new products and services (e.g. in-home networks, smart appliances, new software applications, etc.), including the building of the SM-G systems and supporting consumers who wish to participate. The electrification of the rural areas through MG and RESs will create employment for the teeming population. The self-healing feature includes the intelligence to ensure the safety of grid workers and the general public. This will lead to reduction in the number of injuries and deaths associated with the public's contacts with grid assets. Improved monitoring and decision support systems will quickly identify problems and hazards [58]. The ability to identify equipment that is on the verge of failure is certain to save lives and reduce severe injuries [63].

5. Challenges of the Smart/Micro-Grid in Nigeria context

Despite the numerous benefits of the SM-G as highlighted above, there are still many SM-G challenges to be overcome, as

various countries across the world move towards the adoption of these innovative technologies for delivering the next-generation electricity infrastructures. Many of these challenges have been extensively discussed in Refs. [77,86–88]. They are diverse with most applicable to many countries across the world. Apart from these common challenges, Nigeria has its own peculiar challenges that must be addressed to enable a successful application of these technologies in the country. We summarise these challenges under the following categories.

5.1. Communication technologies

As described earlier, the SM-G systems are complex networks of intelligent electronic devices (IEDs), wired and wireless sensors, smart meters, DERs, and dispersed loads that require cooperation and coordination in order to play their expected role [13,89]. The main driver behind the SM-Gs is the communication technologies (CTs), which will enable a two-way communication between the grid control and monitoring devices and the system operators. There are many ways of achieving two-way communications in SG environment using modern day wired or wireless communication technologies or a mixture of both. Communications can take place via a high variety of technologies such as power line communications (PLC), Universal Mobile Telecommunications System (UMTS), ZigBee, DASH7, WiMAX, and cellular technology such as GSM and General Packet Radio Service (GPRS) [90]. Communication architectures and technologies for SG have been reviewed and discussed extensively in Refs. [91–98].

While most of the CTs are readily available and well developed in advanced and emerging countries, some of these are still relatively unknown in developing countries like Nigeria. Out of these communication methods, only cellular technology is well mature, but there are still many villages and cities in the country that have no cellular station. Moreover, the present cellular stations are not designed for this purpose and using them may result in network congestion or decrease in network performance [99]. The use of PLC is also possible. PLC involves the transmission of Internet traffic through the power distribution cables that run through the customer houses. However, PLC is characterised with low-bandwidth and may only be suitable for devices without stringent requirements. This problem is not limited to Nigeria alone. More research and innovations are needed to overcome this challenge, not only in Nigeria, but also in other countries. Availability of good communications infrastructures is a critical prerequisite for making the SM-G system a reality both in Nigeria and other countries.

5.2. Economic cost

Cost may be a major determinant in the application of SM-G in Nigeria especially at the household levels. The government will need to subsidise the installation cost of the SM-G and electricity generation from RESs as done in advanced countries. Access to affordable capitals and involvement of private investors can help to overcome this challenge. Banks and other financial institutions can participate by borrowing money at low interest rate for long time investments. Government and industries should get involved by allocating substantial research fund for prototypes and demonstrations in SM-G projects before full take off of SM-G in the country.

The on-going economic reform will help create an investor friendly environment for utilisation of SM-G to drive the next-generation electricity grid in Nigeria. However, further efforts including new policies and regulations to provide incentives for capital investment in new technology are urgently needed to stimulate and drive investment in SM-G technology in Nigeria. Support schemes for renewable electricity will also help drive the use of SM-G in the country. An example of these is the Feed-in-Tariffs (FiTs), which are considered as the most effective policy at stimulating the rapid development of RESs [100]. FiTs have been implemented in many European Member States and elsewhere [101,102]. FiT policies provide a promising mechanism that can unlock RE development in Nigeria. Other incentives, such as the one assigned to fossil fuels and subsidies on petroleum products should be extended to the development of RE, to make the technology affordable for the majority of low income earners as well as stimulatory measures to promote RE service provision among public and private investors should be put in place as it is done in Egypt, Malaysia and South Africa [3].

5.3. Social challenge

One of the key social challenges is how to convince the vast majority of the poor people to embrace SM-G. Impoverished people prefer the lowest upfront investment (e.g. diesel electric power generators) to higher investments that pay off over time. This can be attributed to lack of finance and access to loan from financial institutions. These barriers need to be overcome from the onset, since SM-G usually involves a high initial investment and low running costs [70]. MG projects for rural areas must be based on the real needs of the communities. Communities must be actively involved from conception of the projects and in the planning, operation and maintenance of MGs in their environment. Training of local agents in the communities is a major step to get the communities involve. Local agents' knowledge can be combined with the technical expertise, management capacities and financial resources for effective operation of community MGs [103].

5.4. Lack of awareness and reluctance in accepting new technologies

Many people do not know the advantages of the SM-G technologies or renewable energy. Majority of consumers do not even know how electricity is produced and delivered to their homes. Therefore customers, regulators and investors need to understand and be convinced of the benefits of SM-G. The new owners of the PHCN successor companies must be ready for the significant and perhaps radical changes that will take place [104]. Therefore all stakeholders must be properly educated about the benefits of these technologies. Government needs enormous of work in enlightenment campaigns to drive home the important and opportunities of SM-G technologies in powering Nigerian out of the present electricity crisis. The society and the policy makers need to be made aware about the capabilities of SM-G. Academic institutions can help by organising conferences, workshops and seminars to promote and encourage SG-M technologies in the country.

5.5. Security challenge

Another very important challenge is the present insecurity problem in the country. Since most households in Nigeria cannot afford to install any of the aforementioned energy sources or SM-G technologies to fully or partly power their houses due to initial installation cost that is beyond the reach of the common man, the only solution is through investment from the local and foreign investors that can install and maintain such facilities. However, the insecurity in the country is a major threat to attracting major investors from outside the country. No businesses would thrive in an environment where there is no security of life and properties. Although, there are vast opportunities for investment in SM-G and RE in Nigeria, the present level of insecurity in the country is a major hindrance to the attraction of foreign investors into the

country. Examples of insecurity are prevalent in different parts of the country. Kidnapping, bombing and armed robberies are the devils that are inimical to foreign investment opportunities in Nigeria. Concerted efforts need to be put in place to address these problems in order to create a conducive and friendly environment for foreign investors.

5.6. Skilled manpower and technical capacity

SM-G is a relatively new technology that will involve integration of traditional grid, diverse devices, new communications technologies, and plethora of data. This is a complex system that will require knowledge that cut across interdisciplinary boundaries. The traditional power system analysis being taught in the universities and polytechnics is no more sufficient. SM-G will require new modelling and simulation techniques, new design methods, new software tools, new knowledge and skill sets, etc. Presently, the national grid is daily facing lack of power plant components and inadequate capacities to maintain the various units of the existing energy sector. This situation will worsen with adoption of new technologies if no concrete steps are taken to address this trend. There is therefore the need to build indigenous human and manufacturing capacities [8].

Priority should therefore be placed on the development of relevant undergraduate, postgraduate and vocational training to assure the availability of a suitable work force for the next-generation grid in Nigeria. Engineers, technologists, scientists and managers with diverse skill sets are needed to be trained to support the implementation, maintenance, and operation of the systems. This will require investment in both time and money by the government and industrial sector to support education programs for training the skilled manpower needed for SM-G in Nigeria.

5.7. Research and development challenge

As earlier mentioned, the SM-G technologies are still relatively new. Extensive research works by university academics and experts from the industries, including collaborative and interdisciplinary research that cut across university boundaries and significant investment are needed in these areas. Universities need radical review of their science and engineering programme to reflect the current needs of the society. Today, most real-world problems including SM-G technologies are interdisciplinary and require collaborative research projects involving researchers from engineering, science and IT disciplines. Nigeria academics and industrial experts need to be more involved in collaborative research projects that focus on this type of problems. Developing an optimal combination of SM-G technologies will require a significant and sustained R&D investment [77] both from the government and industries.

6. Conclusions

The main objective of electricity power supply system in any nation is to maintain a continuous and sufficient power supply to its customers at a reasonable rate of return. In Nigeria, this objective is far from being met. This has led to many individual, corporations, companies and organisations to seek alternative source of generation to meet their electricity needs with many running at a loss. Hence, the low production level and efficiency affect the level of economy in the country. The need to maintain a reliable and quality electric service to grid-connected consumers, and electrify the rural communities is increasing. This paper discussed the current state of electricity supply system in Nigeria, from generation up to the consumer level including the need for electrification of the rural areas. The concepts of SM-G technologies are described. The technologies are linked to the major problems facing the electricity system in Nigeria and their benefits to the stakeholders in the electric power sector in Nigeria are presented. The key challenges confronting the use of SM-G in the country are analysed and discussed with some suggestions of ways to tackle the challenges. SM-G can help overcome the various inadequacies in the present ageing electric power systems around the world. Adopting SM-G technologies in Nigeria will help boost the energy generation capacity through the integration of DERs at the distribution level as well as the electrification of rural areas. This will reduce the reliance on the inefficient and centrally generated power.

There is no doubt that if Nigeria is to compete with its counterparts in the developed world, it needs to urgently address its present electricity crisis. Solutions based on the modern SM-G can efficiently harness the abundant and God given RESs for tackling this crisis. Economic viability of any nation is highly dependent on its electricity supply system. We argue that the next-generation electricity grid in Nigeria will need to embrace the use of SM-G technologies. The final handling over by the Federal Government of the 15 privatised assets of the unbundled PHCN to the core investors is a good starting point. This should be a major driver to the application of SM-G technologies to the national grid leading to a more efficient and reliable next-generation grid for Nigeria populace. The benefits are enormous but the challenges must be solved. Overcoming the challenges will go a long way to unlock Nigeria's economical and industrial potentials, and move the nation towards economic prosperity. Investment in SM-G technologies will have significant impact on the economic development and further investment in other areas of the economic. Understanding the benefits and challenges of SM-G technologies in the context of Nigeria is crucial to their effective application to the current electric power supply system in the country. The government and the core investors who have taken over the unbundled Nigeria electricity grid urgently need to develop a national road map for SM-G in Nigeria.

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